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Leveraging IoT to Mitigate Information Management & Communication Lapses on Construction Sites.

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ABSTRACT

This paper explores IoT leveraging by construction project management professionals for information management and communication lapses mitigation. An integrative review of a purposive sample of literature exploring implications around leveraging IoT for enhanced information management and communication for construction project management professionals in South Africa. Findings indicates the capacity and pervasiveness of IoT in the global and local construction industry extends to the enhancement in capturing, management, and communication of ubiquitous construction site data in real-time. Literature also shows that CSM shortcomings related to information management & communication can be improved through innovative exploitation of available IoT technologies as supposed to reinvention of technologies from other sectors. The study explored a nascent technology that is at the forefront of digital innovation in construction project management. The study offers a comprehensive view on IoT leveraging for information management and communication enhancement during construction project execution. Furthermore, the study identifies the need for a framework to explore areas of CSM where IoT can also be leveraged beyond health & safety. This paper responds to the theme by looking at IoT adoption in construction project management as a sub concept of digitisation in construction.

KEYWORDS:

IoT, IoT in Construction, Information Management and Communication Lapses, Construction Digitisation.

1. Introduction

The construction industry is at the cusp of a new era where technology applications and tools are transforming design, planning, and execution methodologies (Blanco et al., 2017; Osunsanmi et al., 2020). Management limitations on construction management processes are being eliminated with the provision of advanced software, construction focused hardware, and analytics capabilities (Ram et al., 2019). Nevertheless, the increasing complexity and value of projects are constantly putting construction contractors under immense pressure to reduce costs overruns, improve timeline and efficiency (Agarwal et al., 2020; Hossain and Nadeem, 2019). Digital technologies emerging from technological advancement amid the 4th industrial revolution have caused disruption across all sectors. Digital innovation within construction project management has evolved to computer aided information and communication technologies, as well as digitised data management systems (Reyes Veras et al., 2018; Safa and Hill, 2019). Current trends in proliferation include the development and infusion of integration and collaborative technologies such as Building Information Modelling (BIM), the Internet of Things (IoT), cloud computing and project management software (Elia et al., 2020; Ibem and Laryea, 2014). Hence, technological development within construction is no longer the enablement of model-based information but more complex and integrated data management systems (Agarwal et al., 2016; Chen and Lu, 2019; Ibem and Laryea, 2014). More so now that the global Covid-19 pandemic has forced industry players to abruptly adopt digital strategies in their project delivery methods, the role of technology has become even more important (Booyens and Van Beek, 2020; Harinarain and Naicker, 2019; Mahajan, 2021).

Digitisation of construction execution processes means doing away with manual and paper-based management of construction site activities. It is a data-driven solution that enables improved construction execution practices (Sawhney et al., 2020). A paradigmatic shift towards real-time sharing of information for guaranteed transparency and collaboration, progress fast tracking and quality control for better and more reliable outcomes (Kähkönen and Rannisto, 2015). IoT implementation is one digital strategy that can facilitate in reducing complexity and uncertainty by offering project managers the ability to monitor and modify on-site operations and enhance information exchange to increase productivity and efficiency. The deployment of IoT could be pivotal in transforming the construction industry to enable new functionalities along the entire project value chain (World Economic Forum, May 2016). The WEF (2016) suggest that emerging and developing countries must identify how they can benefit from technological advances already being applied in developed countries. As such, this paper seeks to review how construction project site management professionals can leverage IoT for effective information management and communication. It will highlight tools required in leveraging IoT for enhanced CSM information management and communication. Furthermore, the paper will review challenges currently hindering wide adoption of IoT to aid project management professionals in strengthening their strategies when implementing IoT beyond health and safety.

2. Preliminary Review of Literature

IoT leveraging potential within the construction industry can be rated across phases and functions (Alaloul et al., 2020). Moreover, it can be characterised into four main aspects: digital access; digital data; automation; and connectivity. Digital access describes the possibilities enabled by information and communication (ICT) systems in accessing the internet and enterprise resource planning (ERP) systems. Digital data entails the electronic capture and analysing of data to generate insights regarding processes in the construction project value chain for informed decision making and efficiency improvement. Automation classifies autonomous, machine learning and artificially intelligent systems. Lastly, connectivity characterises the opportunities to integrate and synchronise previously isolated activities and systems (Schober, 2016).

For an environment that is increasingly complex and ephemeral, real-time on-site data capture through IoT can radically improve cost savings, connectivity, greater flexibility, and adaptability (Martinez et al., 2020). Furthermore, in the wake of digital transformation across the project life cycle, it can be argued that a construction process-orientated development of cyber-physical working methods ensure optimal workflow definition, creating basis for standardisation and efficiency improvement. Additionally, real-time capture of on-site processes' data through IoT would outline comparison between intended and actual progress. Thus, enabling substantive forecasts of time and cost during the progression of the construction phase (Atayero et al., 2016; Gubbi et al., 2013; van Wyk and Kajimo-Shakantu, 2019). This would add value in controlling construction progress both to the client and contractor through remote supervision, more detailed documentation, and improved budget security.

2.1. The internet of things (IoT)

The internet of things (IoT) is an integrated framework of innovative applications sharing information across organisational platforms through connected sensors and actuators (Gubbi et al., 2013). Kobusińska et al., (2018) describes IoT as a dynamic and ubiquitous network of interconnected agile devices and sensors embedded to enable scalability, flexibility, and ubiquity in multimedia data processing, storage, access, as well as communications. These devices extract data from social environments and wireless networks provide connection between "things". The promise of IoT lies in the cyber-physical systems with the capability to record, generate and process information previously performed with human shortcomings (Chen et al., 2021).

2.2. IoT in Construction

IoT in construction encompasses the use of wearable or site embedded internet-connected sensors and actuators. These devices enable the collection of certain data regarding activity, performance, and conditions of the

construction site (Gamil et al., 2020; Oke and Arowoiya, 2021). Internet connectivity allows the transmission of this data to dashboards where it is utilised for real-time monitoring of certain construction site aspects. Thus, integrating and translating data into real-time decision-making insights to enhance performance of construction processes. Ergo, IoT has lucrative implications for construction site management in health and safety (safety monitoring), productivity (task management), resource management (asset tracking and monitoring) as well as cost and time saving (site monitoring) (Dilakshan et al., 2021; Dogan and Akcamete Gungor, 2020; Louis and Dunston, 2018). IoT is replacing legacy operational models in their entirety. It is no longer a mere tool to assist in carrying out tasks but a technology that permeates every part of construction execution process (Agarwal et al., 2016). However, several studies focusing on digital technologies within the south African construction industry have highlighted lack in adoption (see (Oke and Arowoiya, 2021; Ozumba and Shakantu, 2014, 2017), recent literature addressing IoT praxes within the industry indicates its proliferation (Aghimien et al., 2019; Arowoiya et al., 2020; Ikuabe et al., 2020; Oke and Arowoiya, 2021; Osunsanmi et al., 2020; van Wyk and Kajimo-Shakantu, 2019).

2.3. Information management and communication (IM&C) as an aspect of CSM

Information management and communication refers to the manner in which information discovered is handled and essentially conveyed to relevant parties (Miao, 2022). It is a term coined by merging the concepts of information management and information communication. The term encompasses the general harnessing of information from information resources to enable utilisation by the right parties for process efficiency improvement (Serema and Mooko, 2014). This aspect concerns how information discovered is organised, accessed and how users can interact with the information (Safapour et al., 2020). Essentially, it describes the entire information life cycle from capturing of operational information for delivery through various channels to the various organisational stakeholders. “The main purpose of communication is to inform or share facts, ideas and opinions for desired actions between sender and receiver” (Lee and Kim, 2018). Fundamentally, communication plays a major role in transferring project specific data and enabling information visualisation (Miao, 2022). Conversely, suboptimal information management with regards to information communication in construction site management leads to delays in the progression of works, defects and at times project failures (Alsafouri and Ayer, 2018; Safapour et al., 2020). Information management and communication as relating to importing timely, accurate information and timely transfer of data affects all other aspects of CSM such as Health and Safety and site material management among others (Dai et al., 2021).

2.4. Construction site management (CSM) and IM&C shortcomings

Construction site management (CSM) is an aspect of site management that encompasses the everyday administration, control and management of resources needed to reduce inefficiencies and optimise outputs in the execution of construction activities (Ozumba et al., 2019; SACPCMP, 2019). CSM depends in part on process variability, flexibility, and the coalescence of resource transforming activities to generate finished outputs. In their findings, confirmed that increased exploitation of technology on construction sites could enhance CSM processes. They noted that prevalent digital tools may also serve as potential mitigation against management shortcomings. IoT tools have capabilities to minimize dependence on periodic information of onsite status from the various stakeholders by offering ubiquitous information and insights of onsite status (Dilakshan et al., 2021; Ikuabe et al., 2020; Wang et al., 2016). Moreover, they enable control and proactive circumvention over site activities and resources (Lee et al., 2018).

3. Research Design for the Study

An integrative literature review technique was used to study how project management professionals can leverage IoT for enhanced information management and communication (Saunders et al., 2016). Subsequent to the literature review, the study identifies strategies in leveraging IoT for IM&C. however, there are challenges that hinder optimal implementation of IoT on construction projects. These challenges are also identified. For the purpose of this paper various sources of literature including journal papers, conference proceedings and industry

publications on the topic were consulted. A review of 36 articles was carried out and the findings are discussed in the section that follows.

In examining the evolution of each research concept within the global and local construction industry over the past ten years, the precise purpose of each search result is previewed to establish how it informs this study. Initially, each concept was studied in its broader context to understand what it is and its constructs. Thereafter, each study was summarised outlining the arguments and deductions made. Lastly, studies were compared and contrasted then grouped thematically. Literature questions were used to ensure that all aspects of the research that needs to be addressed through literature is addressed. To improve the transparency in the review process, sources used comprised of online data bases available through the Wits university library, open Sources: ResearchGate; Google Scholar. Search words included: digital transformation in construction; 4th IR technologies in construction; construction data management; IoT; IoT in construction; IM&C lapses: construction site management shortcomings.

4. Research Findings

4.1. CSM IM&C shortcomings

CSM IM&C shortcomings are those management lapses resulting from limitations of site management in overseeing the construction site management process that affect how information is managed and communicated (Love et al., 2014). Shortcomings emanate from "limitations in the human capacity to ally, direct, track, monitor and control the activities of operatives and movement and utilisation of resources on site" (Ozumba et al., 2019). Crescenzi and Gagliardi, (2018) argue that effective mitigation of such lapses requires technological innovation adoption. This point is also opined by (Ozumba and Shakantu, 2020) who suggest that technology-based process enhancement where technology is infused in construction sites is a need for the effective alleviation of such lapses.

Ismail et al., (2018) envisaged that with the proliferation of innovative technologies within the construction industry, comes significant increase in the volume of data generated in construction projects. Moreover, technological advancements pre- covid-19 was underpinned by the availability of information and data exchange among project stakeholders. Thus, owing to the industry's dynamics and data availability, information management and communication suffers from critical lapses (Xu, 2021). Major shortcomings with regards to IM&C relates to the heterogeneity in information assemblage, and lack of validation as regards information exchange and repository (Ayodele and Kajimo-Shakantu, 2021).

Furthermore, Ayodele and Kajima-Shakantu (2020) argue that challenges in data management arise where inconsistency in the method of information generation affects the effective sharing of such data across platforms. This relays to the challenge of interoperability and incompatibility within databases (WEF, 2017). Other shortcomings with regard to IM&C relate to the lack of clarity in data sets due to poor information quality (Sermet and Demir, 2019), ad hoc information collection, unstructured methods of collecting information (Che Ibrahim et al., 2018; Dallaqua et al., 2021).

Furthermore, there is complexity in matching information sources resulting from the collection and storage of information using different data bases and repositories(Martinez-Rojas et al., 2018). Moreover, there is still a lack of coherence in the way information is captured, managed and communicated, making it difficult for project stakeholders to access such information (Ayodele and Kajimo-Shakantu, 2021). Other IM&C shortcomings are due to the resistance to migrate to more digitally adept methods, lack of uniformity in construction execution, information and data integrity, manual capture of information where data collected is altered making it inaccurate, corrupted and incomplete (Ahmed et al., 2018; Che Ibrahim et al., 2018; Chen et al., 2021; Dallaqua et al., 2021).

4.2. Challenges to effective construction site IM&C in South Africa

While extant literature highlights major shortcomings relating to IM&C, it is also important to review challenges to effective IM&C specific to the South African construction industry. As iterated in the previous section, human limitations on management performance with regard to IM&C in CSM factors how process enhancement is effected to avoid negative effects of variability (Ozumba et al., 2019). Lapses in IM&C are prominent across construction sites in South Africa due to the low-quality information and its communication during construction execution (van Wyk and Kajimo-Shakantu, 2019a). Furthermore, these challenges could be linked to the lack of real-time capacity on construction sites for monitoring, physical representation with regards to information communication, as well as the overall lack of digital convergence) (Ozumba and Shakantu, 2020).

Safapour et al., (2020) suggest that insufficient experience from construction site management impedes the transfer of data and information among project team members at the right time. Consequently, this leads to the decrease of internal communication. This was the case in the study by Ayodele and Kajimo-Shakantu (2021) where they discovered that the lack of expertise relates to the willingness to share information. Diversity in information formats and ad hoc methods of information capture were also discovered as challenges affecting IM&C (Ayodele and Kajimo- Shakantu, 2021; Oke et al., 2018a). Similarly, there is a lack in concise information communication where information collected is not reported comprehensively and in detail (Ikuabe et al., 2020). This links to the context where construction execution information collected is not properly managed due to human limitations in the handling capabilities of such data (Ozumba et al., 2019; Ozumba and Shakantu, 2017) (Ozumba et al, 2019).

Furthermore, there is also a notion that project stakeholders are not exposed to the modules that would improve their expertise with regards to data capture, storage, processing, visualisation, and reporting (Ayodele and Kajimo-Shakantu, 2021). Likewise, there is still the issue of cost considerations based on perception of inherent benefits in employing technological strategies that would enhance IM&C processes (Aghimien et al., 2019). This extends to the difficulty in the collection of information in more structured ways which hinders the level of compatibility with information management systems.

4.3. Digitisation of construction site Information management systems

Kim et al., (2013) note in their study on "on-site construction management using mobile computing technology" the difficulty among construction project stakeholders in collecting and sharing data in real time due to paper-based construction procurement activities. Ibem and Laryea, (2014) suggest that this is because paper-based methods lack capability in capturing, storing, processing, and presenting heterogeneous project information being generated in modern day construction procurement activities. It has become evident that as construction sites are getting denser and increasingly complex, paper-based procurement activities are becoming rudimentary.

Furthermore, simplifying the "integration of complex physical machinery and devices with networked sensors and software" transform the construction industry profoundly and irrevocably (Alaloul et al., 2018; Kudriashov et al., 2016). IoT, mobile and cloud applications, and advanced analytics enable equipment and assets in capturing critical performance parameters (Kalirajan and Babu, 2019; Sivagnana and Babu, 2019). These systems can assist in monitoring productivity and reliability. Moreover, value can be derived from communicated information through advanced analytics to improve efficiency, timelines, and risk management.

4.4. Implementation of IoT in construction projects.

Research shows IoT applications within the construction industry as enabling the capturing and analysis of unparalleled volumes of data (Kobusińska et al., 2018; Tryfon-Bojarska and Winska, 2019), contributing to enlarging current data environments for future big data and analytics (Sawhney et al., 2020). Thus, leveraging IoT presents opportunities to improve construction and operational efficiencies as well as economy (Ghosh et al., 2020). On the other hand, Madakam and Uchiya, (2019) argue that through real-time and high-speed reporting, IoT is anticipated as providing enhanced construction processes control and optimisation. Key IoT technologies making wave within the global construction industry include bricklaying robots, smart helmets, RFID sensors, GPS systems, and drones (Dogan and Akcamete Gungor, 2020).

Currently, the wider application of IoT within the construction industry is on reliable and real-time health and safety monitoring (Jin et al., 2020; Kanan et al., 2018; Mneymneh et al., 2019); automated visual management of construction activities (Burger, 2019; Kim et al., 2013; Louis and Dunston, 2018); as well as material and resource management (Arowoiya et al., 2020; Ghosh et al., 2020; Lieberman et al., 2017). Likewise, the scope of IoT capability is yet to be, through research, extended to data management capabilities to address process need areas as well as advancing big data and analytics within construction.

4.5. Key tools/strategies in leveraging IoT for CSM IM&C

Successful leveraging of IoT processes for data capture requires a dramatic change in internal planning, procurement, and construction processes. (Agaral et al., (2020) recommends four principles for project owners and contractors in exploiting a digital technology for information management.

- Firstly, they recommend transparency and risk sharing in contracts noting that contracts should explicitly outline responsibilities allowing for equitable risk sharing and rewards.

Consequently, to transition to digital information management, project owners and developers need to mandate adoption of digital technologies in contracts.

- Secondly, they recommend return-on-investment alignment where positive effects on cost, schedule, and risk optimisation are measured and communicated to build a compelling case for said technology use. Clients should measure and incentivise digital adoption across their projects while project managers should build their abilities to become digitally adept. It is suggested that midsize projects should be used to develop these capabilities.

- Thirdly, new solutions should be simple and intuitive. Interfaces should be site-personnel friendly and compatible with existing ERP solutions to eliminate spending on upgrading existing platforms. Contractors should ensure that project teams are equipped with the authority and budget to pilot new technologies.

- Lastly, change management is imperative as the importance of change towards active data management systems need to be communicated. Lack of investment in change management could lead to organisational failures similar to those encountered by those that resisted change during previous waves of technology disruptions.

The institute of Interdisciplinary Construction Process Management at the Vienna University of Technology (TU Vien) identify five areas where action is needed in leveraging IoT for SCM data capture (Goger and Bisenberger, 2020). These entails restructuring internal processes in organisational structures; consideration of contractual amendments; ensuring interoperability of software solutions; analysis of suitable processes of construction project procurement; and investment in research and development (R&D).

4.6. Implications of IoT for CSM Information management and communication

Current knowledge on digital technology alignment extends that IoT capabilities are developed by eliciting incremental and radical learning as two modes of organisational learning focusing on both individuals and the organisation as a whole (Dremel et al., 2020). IoT capabilities relating to electronic data management systems (EDMS/CDEs) enable simpler and faster data access, less documentation errors due to the improved quality of documentation, as well as improved efficiency in information related tasks.

Kärkkäinen et al., (2019) suggest that developing a digital information management system on construction sites can contribute to optimising productivity, quality, and safety. In substantiating their claim, they argue that on-site progress reports are often subjective and only minimal operational disruptions are recorded in site meetings. In testing their hypothesis – "if information needs are mapped and categorized, methods for collecting, refining and delivering just the right information at the right time and for the right stakeholders can be constructed" – they develop a situation picture framework. This framework focuses on how information flow could be designed in a holistic manner to increase perception, comprehension, and projection of a digital strategy. Their concept indicates

workflow data levels accessibility focusing on operational information needed and how to acquire, store, refine, and distribute it for enhancing on-site production processes as well as cross project planning.

Furthermore, IoT enables equipment and assets to communicate with one another and deliver critical performance parameters to a central data platform for digital capture which can be measured and processed (Woodhead et al., 2018). Web-based adaptive instrumentation and monitoring systems have capabilities to capture and store field-sensor data, construction progress data, workforce, and vehicle movement. In turn, variances and potential risks onsite can be detected from statistical analysis of such data. More importantly in very dense project sites where there are too many activities happening concurrently (Louis and Dunston, 2018).

5. Discussions and Recommendations

Data is at the heart of the entire project delivery process. Harnessing the right data can enable construction companies to device strategies that prevent scope variances and cost overruns (Dremel et al., 2020). The power of properly harnessed data is fundamental to change in productivity and efficiency improvement. To improve efficiency, control, and project bottom line, there is a need to implement technological solutions that provide real-time capture and processing of construction execution processes' data. This would assist informed decision-making in project control, estimating costs and enterprise management (Ram et al., 2019). However, due to the manual management of construction execution processes and deliverables in developing countries such as South Africa (Safa and Hill, 2019; Agarwal et al., 2020), project monitoring often consists of mainly post hoc documenting leading to late detection of deviations from budget and scope (Kärkkäinen et al., 2019). This late awareness impedes the implementation of timely mitigation measures resulting mostly in severe financial and reputational consequences (Batarseh, 2018; Schuh et al., 2017). The lack of real time monitoring through IoT give rise to delays in conveying on-site activities. The lack of real time remote access to site-based project information give rise to incidents leading to time delays, cost overruns, and loss of material for the contractor (Osunsanmi et al., 2020). Martínez-Caro et al., (2020) argue that amid the 4th IR, it is fundamental to anchor organisational visions, aspirations, missions, and strategies in knowledge creation and data driven technologies. Consequently, the introduction of real-time project monitoring that can enable immediate action to bring projects back on track (Reyes Veras et al., 2018).

Therefore, in the context of the South African construction industry, there is a need to provide real-time data that can enable construction project managers to make informed decisions that will improve controls, efficiencies and contribute positively to the outcome for each project. Thus, addressing lapse in aspects of site management such as information management and communication (IM&C). The application of predictive analysis and machine learning to structured and unstructured data in construction execution optimises decision-making on areas such as workloads, resource management and strategies for maximising efficiency. With increased complexity, scope, scale and rapidity of projects, human limitations on CSM become more prominent. Several human limitations in manual management of on-site activities have been addressed in literature. These include Lack of coordination of on-site activities, improved processes and strategic technology adoption, lack of technology adoption as a reason for poor CSM. Noting that project requirements determine project milestones and consequently, the alternatives, the real-time digital collection, management and communication of project data through IoT could ensure enhanced definition and understanding of project control systems (Sun et al., 2020). This would lead to better uncertainty reduction and improved operational efficiency through operational intelligence (OI). Consequently, this could result in more efficient project planning, monitoring, and controlling. Thus, reshaping the status quo of the South African construction industry.

6. Conclusion

The capacity and pervasiveness of IoT in the global construction industry extends to the enhancement of collection, management, and communication of ubiquitous construction site data in real-time. Literature also shows that CSM shortcomings related to information management & communication can be improved through innovative exploitation of available IoT technologies as supposed to reinvention of technologies from other sectors. Nevertheless, there is acute lack of effort in actualising real-time information management and communication within CSM to cover lapses in various areas of CSM where increasing human resources has been

ineffective. Specifically, when IoT is applied to complex heterogenous construction project planning, scheduling, and controlling processes to drive better CSM operational intelligence). Technological advancement pertaining to the construction industry (weather natural or forced by the Covid-19 pandemic) is redefining construction data discovery. IoT has enabled real-time cyber-physical systems to generate and communicate heterogenous data sets from numerous construction activities.

As noted, the effects of industry 4.0 and the accompanying ground-breaking technologies are unavoidable even to the conservative and bureaucratic South African construction industry. Therefore, developing digital approaches to leveraging project site data seems imperative. The intended outcome of the study was to heighten awareness of the vast potential of IoT through highlighting the benefits discovered in attempting to conceptualise a real-time information management and communication framework. Thus, advancing knowledge areas, understanding and practice among South African construction project management professionals and academics regarding leveraging IoT for multiple process need mitigation in CSM.

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